3.2 Static Radar Cross Section Sensitivity Analysis

When a target is illuminated by an electromagnetic wave, it disperses incident energy in all directions. This spatial distribution of energy is called scattering. Radio frequency energy scattered back to the source of the wave, called backscatter, constitutes the radar echo of the target. The intensity of the echo is described explicitly by the radar cross section (RCS) of the object.

Real radar targets are complex reflectors, which can be defined as a non-uniform array of scattering centers such that the RCS varies as a function of viewing angle. The radar cross section can also be defined as scattering efficiency, which is the ratio of the power density of the signal scattered in the direction of the receiver to the power density of the radar wave incident on the target. Thus, for a target in the far field, the radar cross section can be expressed as:

$$\sigma = \left| \frac{E_s^2}{E_o^2} \right| \qquad (3.2\text{-}1)$$

where E_o = magnitude of the electrical field component of the incident electromagnetic field

E_s = magnitude of the electrical field component of the scattered electromagnetic field in the direction of the receiver

For convenience, the target scattering efficiency is interpreted as the cross section of an equivalent isotropic reflector. The RCS is expressed as the projected area of a perfectly conducting sphere which is large compared to the wavelength and which, if substituted for the target, would scatter the same power back to the radar.

While some radar models compute RCS using scattering center theory or the more complex physical and geometric optics theory, many use this equivalent isotropic reflector in the form of an input matrix of statically measured or estimated RCS values as a function of target aspect angle. With this method the RCS is not computed from the incident and scattered electromagnetic fields, but instead uses the experimentally measured RCS. The radar-to-target aspect angle is determined within the model, and the value of the RCS for the particular aspect is selected from an array of input RCS values. Since the RCS consists of measured data, it can be considered a valid function.

The measurement of a target’s RCS is defined for specific radar frequencies, at specific aspect angles having finite resolution. Using this measured data at other aspect angles can lead to errors in predicting the amplitude of received target signals. Another source of error due to RCS data resolution occurs during the process of measuring RCS. Using static RCS measurement facilities, such as RATSCAT, the RCS is typically measured in 0.1^0 increments and then averaged over 1.0^0 or greater cells. The averaging of the RCS data tends to smooth RCS “spikes” emanating from target specular points. This can lead to erroneous estimates of target detection, particularly at target aspect angles where the specular reflection occurs.

ALARM uses a table of RCS values indexed by aspect angle. At aspect angles for which there are no explicit input values, the RCS is determined by interpolation of the nearest values. For targets having high-amplitude specular reflections occurring over small angular areas, the input RCS data may have insufficient resolution to adequately represent the target.

3.2.1 Objectives and Procedures

The objective of the sensitivity analysis of the static RCS functional element is to determine the impact of target RCS resolution on the derived values of RCS used by the model (FE-level analysis) and target detection range (model-level analysis).

At the function level, the measure of effectiveness (MOE) used to determine sensitivity is a 3 dBsm difference in generated RCS value at any point in the flight paths, when comparing the test cases with the baseline case. At the model level, the MOE is a greater than 5% change in the normalized mean detection range, when comparing the test cases with the baseline case.

To conduct the sensitivity analysis, a set of synthetic RCS values for three different resolutions was developed. First, the target was described as a "scattering center" with an arbitrary number of uniformly spaced scattering centers; RCS values were generated in 0.1° increments. This was the baseline RCS table. The tables for the two test cases were then developed by averaging the 0.1° RCS data over 1° and 4° intervals.

Function-level sensitivity analysis requires examination of the generated RCS vaues (variable SIGMAT, the parameter returned by subroutine GETRCS, used to transfer the value of RCS into the overall model). The analysis procedure is to exercise ALARM in the Flight Path mode using the three RCS tables described above and compare the values of RCS generated at each flight path point during the three model runs. The flight path is straight and level at 500 m, flying north to south at 500 knots.

For the model-level sensitivity analysis, ALARM is run in Contour Plot mode, using the three RCS tables described above. The target’s altitude is 500 m, and its speed is 500 knots.

Table 3.2-1 identifies the specific parameters varied, and the output variables recorded, during each ALARM run.

Table 3.2-1 ALARM Runs for Static RCS Sensitivity Analysis

Sensitivity Parameter	Analysis Level	Input Variable	Range of Variation	Output Variable	Test Case Description
Static RCS resolution	FE	DELAZD	**0.1˚**, 1.0˚, and 4.0˚ RCS increments	SIGMAT	Run ALARM in Flight Path mode; target body RCS= 1.0 m^2; target speed=500 kts
		RCSIN	RCS signature averaged for size of RCS increment		
	Model	DELAZD	**0.1˚**, 1.0˚, and 4.0˚ RCS increments	SIGTOI	Run ALARM in Contour Plot mode; target body RCS=1.0 m^2; target speed=500 kts.
		RCSIN	RCS signature averaged for size of RCS increment.		
Note: Values in **bold** indicate baseline case.					

3.2.2 Results

Figure 3.2-1 is a plot of the derived target RCS taken at 0.1^0 increments for 360^0 in azimuth and at 0.0^0 elevation plane of the target aircraft. As is typical of measured RCS, the high-resolution data were averaged over 1.0^0 and 4.0^0 cells. The averaged RCS data plots for 1.0^0 and 4.0^0 cell increments are shown in figures 3.2-2 and 3.2-3, respectively. As can be observed in viewing the three plots, the cell averaging process tends to reduce the RCS speculars. For example, the nose-on RCS at 0.1^0 resolution is approximately 0 dBsm, while the nose-on RCS values at 1.0^0 and 4.0^0 resolution are -5.0 dBsm and -6.0 dBsm, respectively. These RCS data were used as input to the ALARM model to evaluate the impact of RCS resolution on the generated values of RCS used in ALARM to compute target signal.

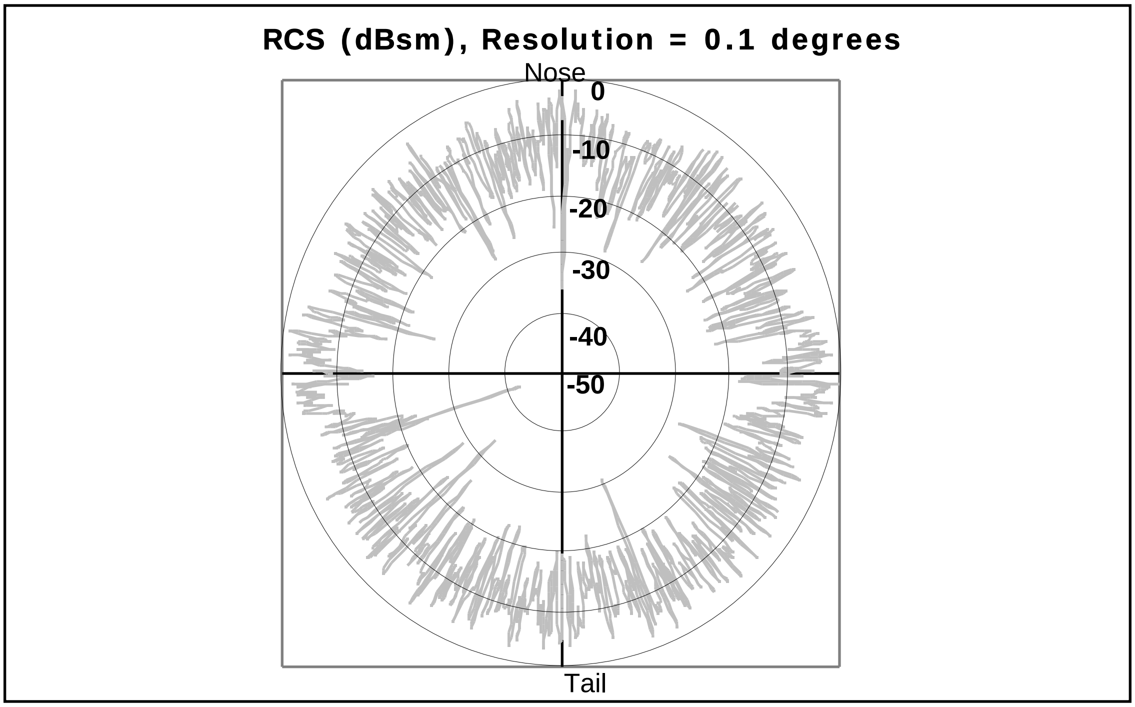

Figure 3.2-1 Derived Target RCS (0.1˚ Resolution)

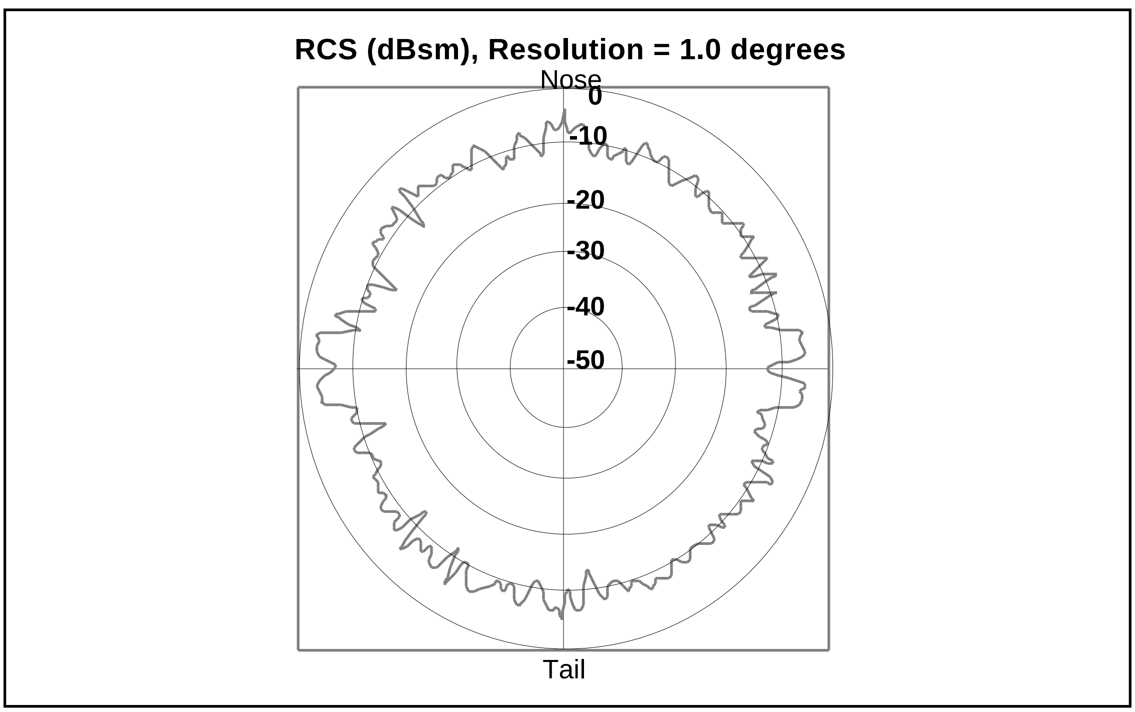

Figure 3.2-2 Derived Target RCS (1˚ Resolution)

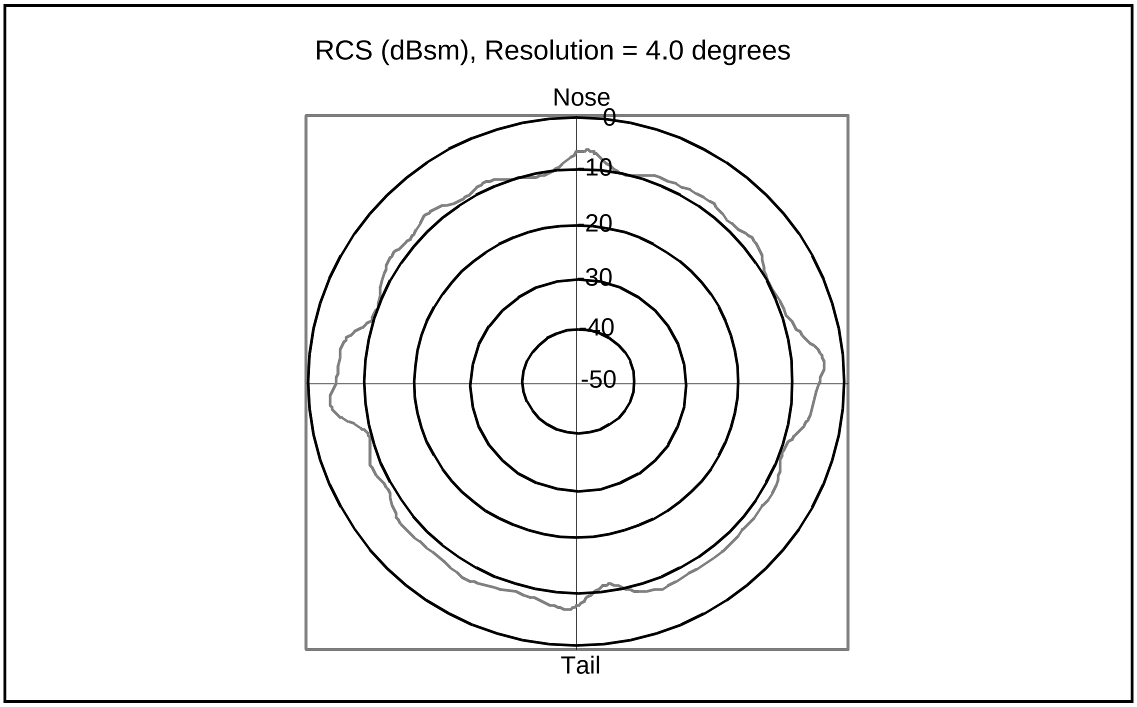

Figure 3.2-3 Derived Target RCS (4˚ Resolution)

Figure 3.2-4 is a family of plots of the ALARM-generated RCS values for an offset flight path to the victim radar, for each of three resolutions 0.1˚, 1˚, and 4˚. There are observable differences in the ALARM-generated values of RCS as the RCS input resolution decreases. For example, at flight path point 62, the differences in the generated RCS relative to the baseline value are -6 dBsm (1^0 case) and -5 dBsm (4^0 case). These differences are significant, exceeding the 3.0 dBsm threshold criteria for this functional element.

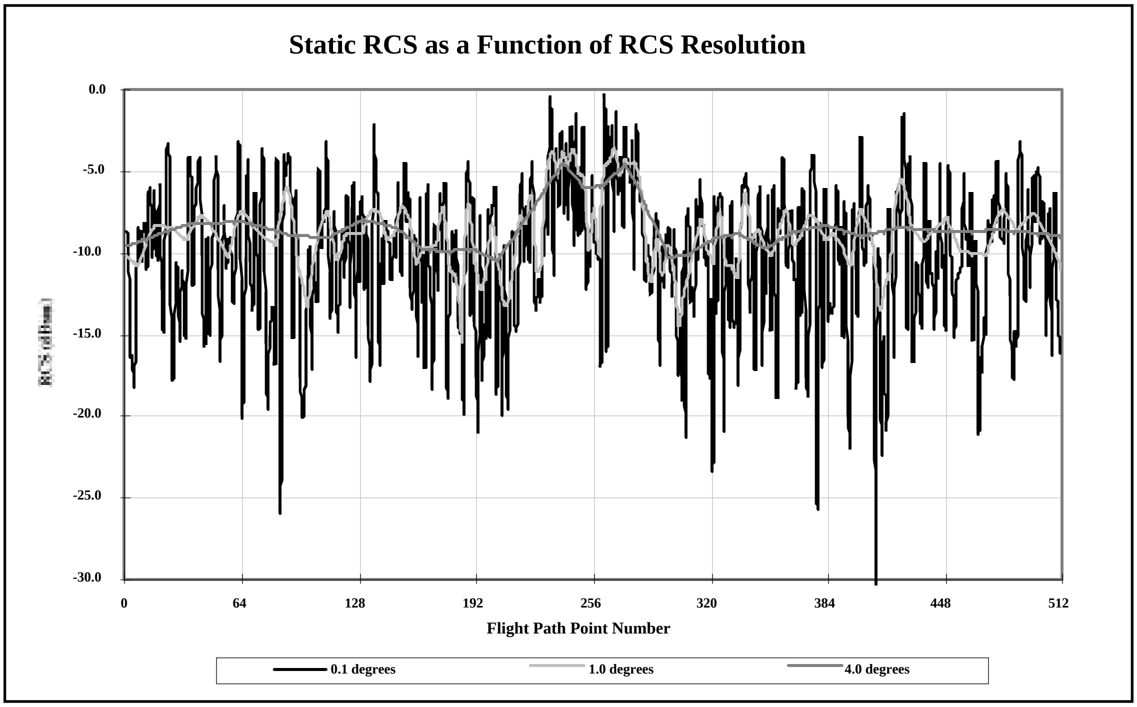

Figure 3.2-4 ALARM-Generated Target RCS

The impact of RCS resolution on target detection range is shown in figure 3.2-5, a plot of maximum target detection range vs. target offset flight path range as a function of target RCS resolution. It is apparent that at the highest target signature resolution (i.e. 0.1^0) the target is detected at greater ranges relative to the target represented by lower-resolution RCS. The normalized mean difference in target detection range for target RCS resolutions of 1.0^0 and 4.0^0 relative to the target detection range of the target having 0.1^0 resolution is 9.19% and 11.08%, respectively, which are significant differences.

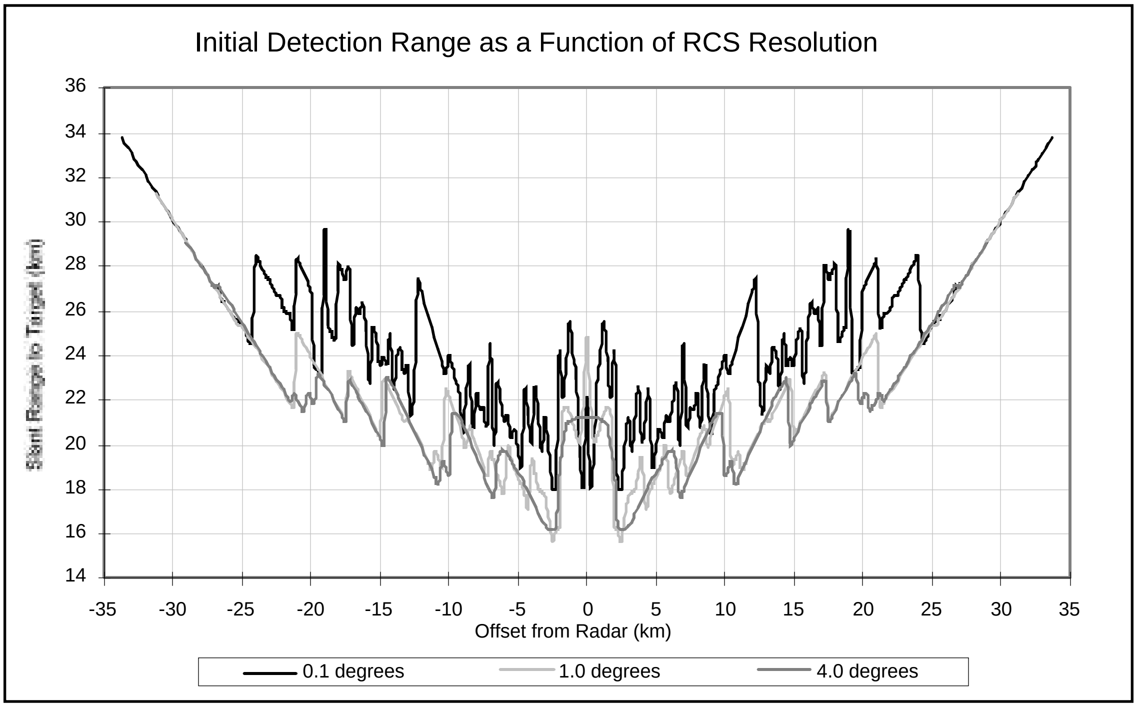

Figure 3.2-5 Initial Detection Range as a Function of RCS Resolution

Table 3.2-2 Detection Range Statistics as a Function of Changes in RCS Resolution

RCS Resolution	Mean (m)	σ (m)	Normalized Mean Difference	% Change
0.1˚ (baseline)	24970	3.61	-	-
1˚	22539	3.59	–0.048	–9.19
4˚	21691	3.04	–0.059	–11.08

3.2.3 Conclusions

The ALARM estimate of target detection range was shown to be sensitive to the angular resolution of target RCS. However, validation of the Static RCS functional element requires only parameter validation since RCS is a model input. Because RCS resolution has a significant impact on the prediction of target detection, it should be measured at an angular resolution of at least 0.1° in both azimuth and elevation planes. It is important to note that the measured radar cross section of the target is a required parameter for model-level validation of other functional elements and will retain the same measurement resolution requirement.

The ALARM model user should be aware that the use of cell-averaged data over large resolution cell limits may lead to significant errors in determining target detection range. This may be particularly applicable to low-observable targets which will typically have low average cross section but will likely contain a few high RCS specular points. These specular points will not be observable if using RCS which has been averaged over large angular cell limits.